THE ASTROPHYSICAL JOURNAL, 603:330–334, 2004 March 1

SOLAR FAST-WIND REGIONS AS SOURCES OF SHOCK ENERGETIC PARTICLE PRODUCTION

S. W. KAHLER
Air Force Research Laboratory, Space Vehicles Directorate, 29 Randolph Road, Hanscom Air Force Base, MA 01731; stephen.kahler@hanscom.af.mil
Received 2003 September 2; accepted 2003 November 13

ABSTRACT

If the production of solar energetic particles (SEPs) near the Sun is due to shocks driven by coronal mass ejections (CMEs), then two factors might favor SEP acceleration in slow rather than fast solar wind streams. The first is that both the MHD fast-mode and solar wind flow speeds are higher in the fast-wind streams. The second is that shock seed populations in the fast-wind streams consist of weak suprathermal ion tails with soft spectra. An earlier study used observed fast west-limb or halo CMEs and solar wind O^{+7}/O^{+6} ratios to compare associated SEP events and fast CMEs in fast wind with those in slow wind. Properties of the few fast CMEs in fast-wind regions suggested a bias in terms of associated SEP event size and/or CME speed against shock production of SEPs in fast-wind regions. Here the previous 1998–2000 study is expanded through 2002. The results of the much larger event sample now show no significant bias against SEP production in fast-wind regions. We discuss the implications of this result for shock seed populations and for shock propagation in coronal fast-wind regions.

Subject headings: Sun: corona — Sun: coronal mass ejections (CMEs) — Sun: particle emission

1. INTRODUCTION

A correlation between the peak intensities I of $E > 10$ MeV gradual solar energetic particle (SEP) events observed at 1 AU and the speeds $v_{\rm CME}$ of associated fast coronal mass ejections (CMEs) has long been known. This is understood to be a result of SEP acceleration in the corona and interplanetary medium by shocks driven by the fast CMEs (Kahler 2001a). The correlation, however, shows significant scatter of up to 3 or 4 orders of magnitude in I. This indicates that the CME speed alone is only one factor in SEP production by driven shocks and that other factors must also be important (Kahler, Burkepile, & Reames 1999). The problem is to identify those other factors. Kahler (2001b) identified enhanced ambient SEP intensities and spectral variations among SEP events as two factors contributing to the scatter of the correlation between $\log I$ and $v_{\rm CME}$. Here we consider the required coronal and interplanetary shock wave speeds and suprathermal seed particles as other possible factors.

1.1. *CME Speeds in Fast Solar Wind*

To drive a shock, a CME speed $v_{\rm CME}$ must satisfy the condition $v_{\rm CME} > v_{\rm flow} + v_{\rm fast}$, where $v_{\rm flow}$ is the solar wind flow speed and $v_{\rm fast}$ is the solar wind MHD fast-mode speed. It is of interest to see how $v_{\rm flow} + v_{\rm fast}$ varies through the different regions of the corona and inner heliosphere. Kahler & Reames (2003, hereafter KR03) reviewed work that established that the characteristic speeds of the fast-wind streams considerably exceed those of slow-wind streams, although the differences are difficult to quantify, especially at solar maximum, when small coronal holes are the main sources of the fast-wind streams. Since SEPs follow the magnetic field lines convected antisunward by the solar wind, the SEPs observed in solar fast-wind streams at 1 AU must be produced in the same streams near the Sun, as shown schematically in Figure 2 of KR03. KR03 used wide (>60°) and fast ($v_{\rm CME} > 900$ km s^{-1}) halo or west-limb CMEs as candidates for producing gradual SEP events at 1 AU. The 20 MeV proton intensities from the EPACT (Energetic Particles: Acceleration, Composition, and Transport; von Rosenvinge et al. 1995) instrument on the *Wind* spacecraft were used to identify associated SEP events.

KR03 used the solar wind O^{+7}/O^{+6} ratios measured by the SWICS (Solar Wind Ion Composition Spectrometer; Gloeckler et al. 1998) on *ACE* to identify fast-wind regions near the L1 point. Low values of that ratio have been shown to correlate well with fast-wind regions during solar maximum (Wang & Sheeley 2003; Zhang et al. 2003). The O^{+7}/O^{+6} ratios did not order the peak 20 MeV SEP intensities, even when variations in CME speeds and solar source longitudes were taken into account. With the criterion that $O^{+7}/O^{+6} < 0.15$ to confirm the identifications of fast-wind regions (Zurbuchen et al. 2002), KR03 found that 5 of the 11 fast CMEs observed in fast wind were associated with SEP events. That fraction of CMEs in fast wind was smaller than that for the remaining CMEs, 56/73, for which the solar wind signature was $O^{+7}/O^{+6} \geq 0.15$. In addition, the median speed of the five fast-wind CMEs with SEP events was 1336 km s^{-1}, while that of the other 56 SEP-associated CMEs was only 1103 km s^{-1}. CMEs without associated SEP events in the fast- and slow-wind groups had more comparable median speeds, 1070 and 1017 km s^{-1}, respectively. The higher median speeds of SEP-associated CMEs and the lower fraction associated with SEP events for the CMEs in fast-wind regions suggested a possible bias against SEP production in the fast-wind regions, but the statistics of the KR03 study were obviously too small for a definitive determination.

1.2. *Shock Seed Particles in Fast Solar Wind*

The injection problem (Zank et al. 2001) is to determine how ions are preenergized to sufficient energies to be Fermi-accelerated in shocks. A role for ambient SEPs as seed particles for subsequent gradual SEP events was suggested by Mason, Mazur, & Dwyer (1999) on the basis of ^{3}He ions observed in the gradual SEP events. Those ions were assumed to be produced in earlier flare impulsive SEP events and to linger in the inner heliosphere until accelerated by later CME-driven shocks. Observational evidence indicates an important role for such remnant ions in large gradual SEP events (Tylka et al. 2001) and in interplanetary shocks (Desai et al. 2001, 2003). Kahler (2001b) has also found that at 1 AU enhanced levels of ambient energetic ($E > 10$ MeV) protons correlated with the peak intensities of gradual SEP events. However they are produced, it appears that ambient ions of suprathermal energies are important, if not necessary, for SEP events.

Recent work (Gloeckler 1999; Gloeckler et al. 2000) has established that suprathermal tails in the ion speed distributions extending to at least 10 $v_{\rm flow}$ are common in the solar slow-wind regions but are very weak and soft in the fast-wind regions of polar coronal holes (Gloeckler 2003). In corotating interaction regions (CIRs), those tails are not produced in the shocks but are enhanced in the turbulent regions between the forward and reverse shocks (Schwadron, Fisk, & Gloeckler 1996). However, the ions in those tails do serve as seed particles for the $E > 1$ MeV ions produced in the CIR shocks (Mobius et al. 2002) and in at least one case for SEPs from an interplanetary shock (Bamert et al. 2002). If the ion tail distributions observed at 1 AU and out to 5 AU are similar to those near the Sun, then the fast-wind regions would again appear to be unlikely sources of SEPs produced by CME-driven shocks. It therefore becomes important to determine whether $E > 10$ MeV SEPs are accelerated as readily in fast-wind regions as in slow-wind regions.

2. DATA ANALYSIS

In their study KR03 selected for analysis fast ($v_{\rm CME} > 900$ km s^{-1}) CMEs appearing as halos or on the west limb and with solar source region identifications during the period 1998–2000, when O^{+7}/O^{+6} values from the *ACE* SWICS instrument were available on the *ACE* Web site.[1] In addition, they added all CMEs associated with gradual SEP events during the same period. Their primary result was based on CMEs with source regions from W30° to behind the west limb and a requirement that CME width be greater than 60° after KR03 found that only one CME with a reported width less than 60° was associated with a SEP event of their study. To determine whether a given CME was associated with a SEP event, the ambient 20 MeV proton intensity $I < 10^{-2}$ protons cm^{-2} s^{-1} sr^{-1} MeV^{-1} was required.

The CME linear fit speeds were taken from the *SOHO* LASCO CME catalog Web site,[2] which has recently been updated through the end of 2002. Here we extend the KR03 study from 1998 through the end of 2002, but with two changes in our CME selection criteria. First, we extend the solar source regions to a longitude range of central meridian to behind the west limb. CMEs without associated EUV or X-ray enhancements on the disk or west limb were considered backside events and not included in the study. Second, we include all CMEs with widths $\geq$40°, since three cases of SEP events with associated CMEs narrower than the $\geq$60° width limit of KR03 are included.

The total number of fast and SEP-associated CMEs for the period 1998–2002 is now 165. That includes 111 SEP events, of which 12 occurred in fast-wind ($O^{+7}/O^{+6} < 0.15$) regions, and 54 CMEs without associated SEP events, of which 13 occurred in fast-wind regions. Figure 1 shows O^{+7}/O^{+6} ratios

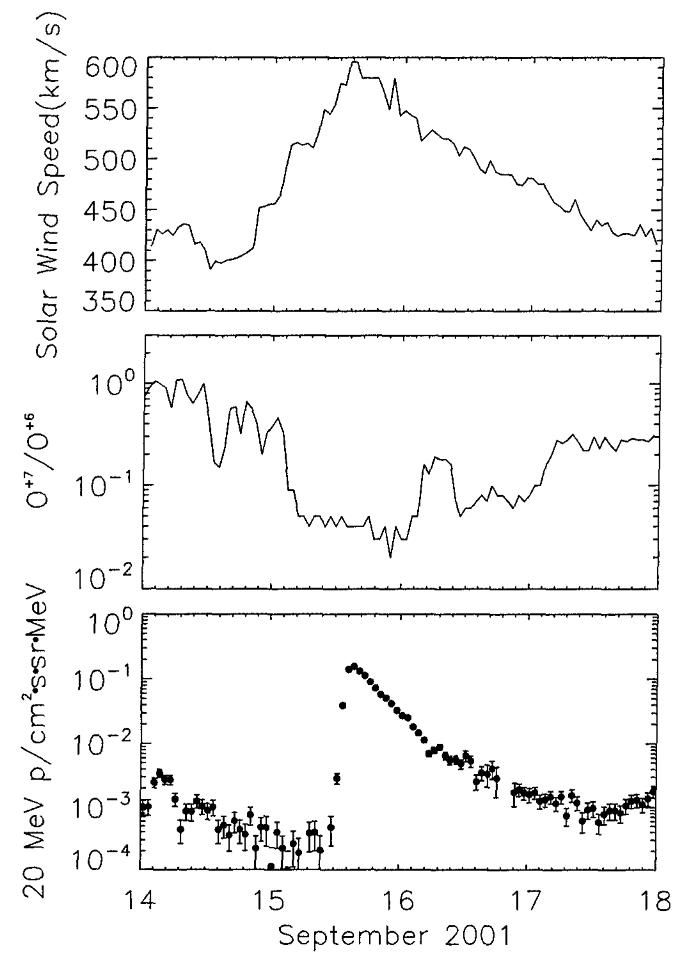

FIG. 1.—Plots of solar wind speed $v_{\rm flow}$ (*top*), O^{+7}/O^{+6} ratios (*middle*), and 20 MeV proton intensities (*bottom*) during the SEP event of 2001 September 15. The SEP event occurred in a high-speed stream, as indicated by both a high solar wind speed and a low O^{+7}/O^{+6} ratio. The speed of the associated CME was only 478 km s^{-1}, well below the expected required speed to drive a shock in a fast-wind region.

during the time of the onset of the 2001 September 15 SEP event. That event is also noteworthy because of the low leading-edge $v_{\rm CME}$ of 478 km s^{-1} measured for the CME, well below the expected $v_{\rm CME}$ of 1000–2500 km s^{-1} required for shock production in fast-wind streams at $\sim$10 $R_\odot$ (KR03). Since the associated flare occurred in AR 9608 at S21°,W49°, the projected sky speed should not be substantially lower than the intrinsic speed.

In Figure 2 we show the logs of the 20 MeV peak intensities I versus the associated CME speeds for the 165 CMEs. When no associated SEP event was found, log I (20 MeV) was set equal to -3.52 for the CME. The large spread of points is due partly to the broad solar longitude range of the CMEs. The two populations of Figure 2 appear to overlap with no obvious differences. The SEP associations and median speeds of CMEs of the two populations are compared in Table 1. We find that 12 of the 25 (48%) fast CMEs with $O^{+7}/O^{+6} < 0.15$ are associated with SEP events, somewhat less than the 71% (99 of 140) value for fast CMEs with $O^{+7}/O^{+6} \geq 0.15$, which we will call slow-wind regions. We can expand the statistical base by adding the previously excluded sample of 48 eastern hemisphere fast CMEs, 5 of which occurred when L1 was in fast wind. The association totals for 213 CMEs at all longitudes are then 16 of 30 (53%) CMEs in fast-wind regions and

[1] The *ACE* SWICS_SWIMS Level 2 Data Web site is available at http://www.srl.caltech.edu/ACE/ASC/level2/lvl2DATA_SWICS_SWIMS.html.

[2] The *SOHO* LASCO CME catalog Web site is available at http://cdaw.gsfc.nasa.gov/CME_list.

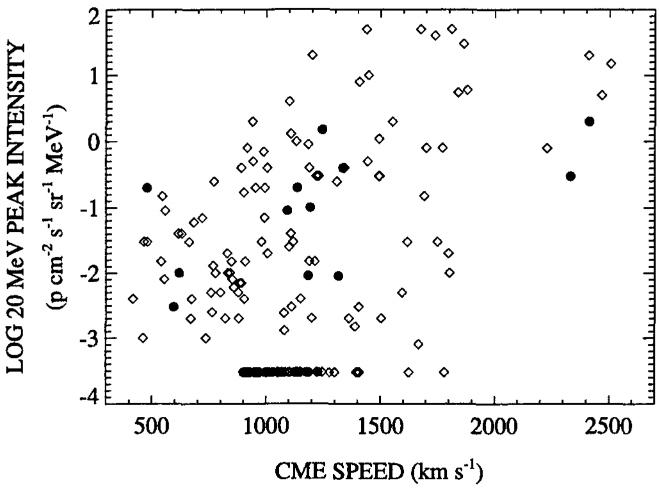

FIG. 2.—Plot of logs of 20 MeV peak intensities I vs. associated CME speeds for western hemisphere source regions. Circles are the 25 CMEs occurring when $O^{+7}/O^{+6} < 0.15$ at L1, and open diamonds are the 140 CMEs from 1998 to 2000 with $O^{+7}/O^{+6} \geq 0.15$. Points at $\log I = -3.52$ correspond to CMEs with speeds greater than 900 km s^{-1} but no associated SEP events. No difference between the distributions of the two groups is obvious.

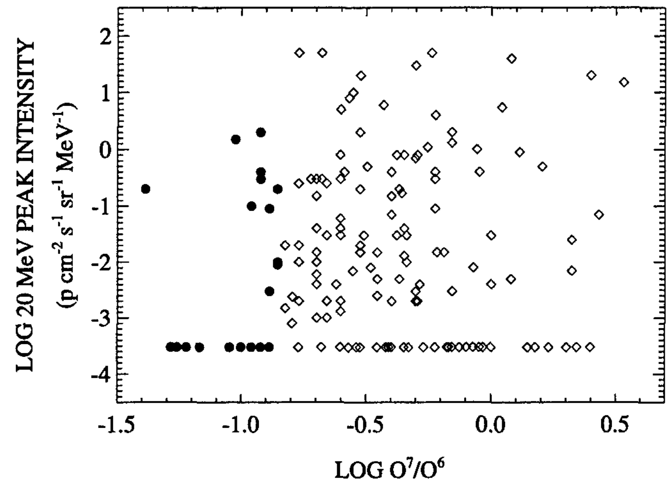

FIG. 3.—Plot of logs of 20 MeV peak intensities I vs. logs of O^{+7}/O^{+6} ratios for fast CMEs. Circles and diamonds are as in Fig. 2. No trend is apparent in the plot.

124 of 183 (68%) CMEs in slow-wind regions that are associated with SEP events. This establishes that SEP events do occur in fast-wind regions.

Table 1 shows that the median $v_{\rm CME}$ of SEP-associated CMEs with $O^{+7}/O^{+6} < 0.15$ is slightly faster (1187 vs. 1099 km s^{-1}) than that of SEP-associated CMEs with $O^{+7}/O^{+6} \geq 0.15$. Speeds for all four groups of the table are fairly comparable, although the SEP events include CMEs with $v_{\rm CME} \leq 900$ km s^{-1}, while the non-SEP events are restricted to $v_{\rm CME} > 900$ km s^{-1}.

Figure 3 is a plot of the logs of the 20 MeV peak SEP intensities against the logs of their associated O^{+7}/O^{+6} values. We might expect that CMEs with $O^{+7}/O^{+6} < 0.15$ would be associated with weaker SEP peak intensities, but no clear difference between the two populations is apparent.

3. DISCUSSION

The higher fast-mode and solar wind flow speeds of solar fast-wind regions where CME-driven shocks might accelerate the energetic particles of gradual SEP events should make shock production more difficult there than in the slow-wind regions. This difference should be important in the 2–20 $R_\odot$ regions observed by the LASCO coronagraph, since that is where most of the energetic SEP production is expected (Kahler 1994).

On the basis of only 11 fast CMEs in fast-wind regions in their survey, KR03 concluded that the existence of SEP events in fast-wind regions was marginal and that they had only weak evidence that faster CMEs were required to produce SEPs in fast-wind regions. Our expanded survey of 25 fast or SEP-associated CMEs in fast-wind regions now clearly establishes SEP production in fast-wind regions as a common phenomenon. For 3 of the 12 SEP-associated CMEs of Figure 2, $v_{\rm CME} < 620$ km s^{-1}, showing further that enhanced speeds in fast-wind regions are not a requirement for SEP production, which we assume results from CME-driven shocks. In our study we have required the fast CME to occur when $O^{+7}/O^{+6} < 0.15$ at L1. In several other cases a fast CME occurred just prior to such a period, and a peak in the SEP intensity-time profile was clearly seen when $O^{+7}/O^{+6} < 0.15$.

The surprising result that SEPs occur commonly in fast-wind regions suggests that we should reexamine the basic assumptions motivating the study. These are that the $v_{\rm CME}$ speeds required for shock formation and SEP acceleration near the Sun are much higher in fast-wind regions than in slow-wind regions and that suprathermal ion tails are required for ion injection into the shock acceleration process. The latter assumption is based on evidence that suprathermal ions serve as seed particles for gradual SEP events and for traveling interplanetary shock SEP events, as discussed in § 1.2. We therefore take the reported weak and soft suprathermal tails on fast-wind ion speed distributions (Gloeckler 2003) as one reason to expect a deficit of SEP events in those regions. Recently, however, Mewaldt et al. (2003) used a simple model to calculate the remnant suprathermal Fe densities integrated above 10 keV nucleon^{-1} (corresponding to a few times the ambient solar wind speed) to see whether they were sufficient to account as seed particles for the abundances of Fe in a number of normal and "hybrid" gradual SEP events. They found the remnant populations to be ~10–100 times too small to explain the gradual SEP event Fe abundances above 40 keV nucleon^{-1}, although adequate for the higher (>1 MeV nucleon^{-1}) energies. Our observation of SEP events in fast-wind regions is also difficult to understand if suprathermal ions are required as seed particles for gradual SEP events and those suprathermal ion abundances are weak in fast-wind regions.

The CME speed requirement given by KR03 for coronal shock generation was $v_{\rm CME} > v_{\rm flow} + v_{\rm fast}$. If we assume a CME with a radially propagating front and azimuthally expanding flanks in a generally radial magnetic field in the

TABLE 1
SEP ASSOCIATIONS AND CME SPEEDS

CME Group	Number of CMEs	Median Speed (km s^{-1})
With SEPs, $O^{+7}/O^{+6} < 0.15$.....	12	1187
With SEPs, $O^{+7}/O^{+6} \geq 0.15$.....	99	1099
No SEPs, $O^{+7}/O^{+6} < 0.15$........	13	1012
No SEPs, $O^{+7}/O^{+6} \geq 0.15$........	41	1064

coronal region 3–20 $R_\odot$, we can be more specific about the speed requirements. CMEs arise from closed field eruptions at the bases of slow-wind regions (Low 2001; Wu, Andrews, & Plunkett 2001), so drivers of the fast-mode shocks in the adjacent fast-wind regions must be the lateral expansions of the CME flanks toward those regions, as shown in Figure 4. Since the azimuthal flank expansions are quasi-normal to the radial solar wind flows, the speed requirement for shock generation may be relaxed to $v_{\rm CME} > v_{\rm fast}$. On the other hand, since the shock in this simple case would be a quasi-perpendicular shock, $v_{\rm fast} \approx (v_{\rm A}^2 + c_s^2)^{1/2}$, while for a quasi-parallel shock, more appropriate for the slow-wind regions ahead of the CME leading edge, $v_{\rm fast}$ is only the greater of $v_{\rm A}$ or c_s, where $c_s \approx 170$ km s^{-1} is the sound speed and $v_{\rm A}$ is the Alfvén speed. Thus, while the required CME speed in the fast-wind regions is decreased because the flank expansion is quasi-normal to the flow speed, it is also enhanced because of the higher $v_{\rm fast}$ across the radial magnetic fields. If $v_{\rm flow} > c_s$, the result could be a net decrease in the $v_{\rm CME}$ requirement for shock production in fast-wind regions.

Even if the $v_{\rm CME}$ requirement for fast-wind regions is reduced, it may still exceed the CME flank expansion speeds toward those regions. CME flank speeds have not been systematically measured, but comparisons between CME angular spans measured in the inner and middle corona indicate only modest 20%–30% increases (St. Cyr et al. 1999), and even those increases may be due to accumulations of coronal material with height rather than true angular expansions. Nevertheless, streamer deflections accompanying some fast CMEs have been obvious from the first CME observations (Gosling et al. 1974) and have been interpreted as CME-driven magnetoacoustic shock waves (Hundhausen 1987). Sheeley, Hakala, & Wang (2000) found that those disturbances appeared in coronagraph images as kinks moving radially outward along streamers and raylike features (Fig. 4). KR03 suggested that SEP production by shocks in fast-wind regions may occur in polar plumes, where $v_{\rm flow}$ and $v_{\rm fast}$ speeds are substantially lower than in the interplume regions (Teriaca et al. 2003), which are the dominant sources of the fast wind (although Gabriel, Bely-Dubau, & Lemaire 2003 present a dissenting view). MHD waves in the corona are subject to significant refraction away from regions of high $v_{\rm fast}$ (Wang 2000), so their continued propagation through fast-wind regions surrounding the plumes is not always certain. The observation of significant wave activity in coronal regions observed tens of degrees away from fast CMEs suggests, however, that MHD shocks do propagate through fast-wind regions, although the shock characteristics are still poorly defined.

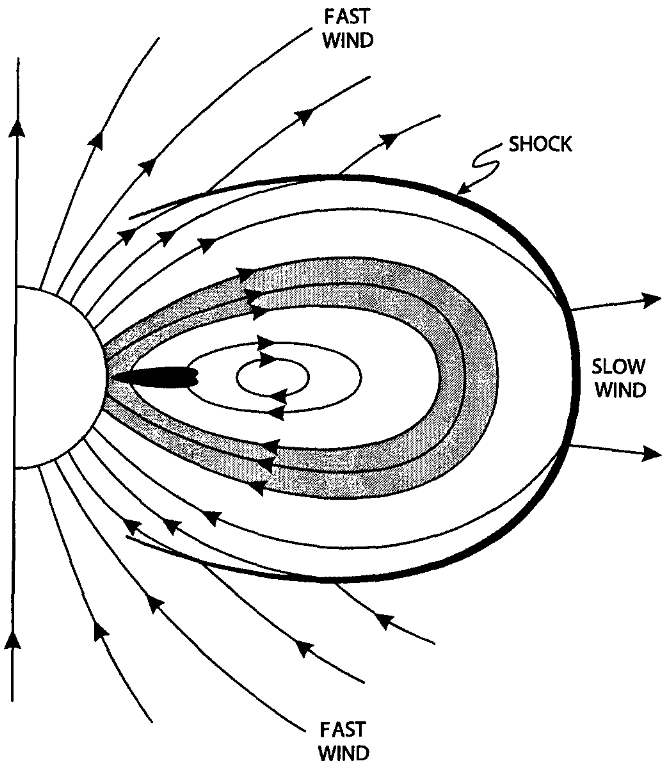

FIG. 4.—Schematic of expanding CME (*shaded region*) with enclosed cavity and filament (*dark region*) driving an MHD shock (*heavy line*). Fast-wind regions are shown with open magnetic field lines (*solid lines*) on both flanks of the CME. The shock is quasi-normal in the fast-wind regions and quasi-parallel in the slow-wind regions above the CME. Open field lines within the shock are bowed outward, creating antisunward moving kinks at the shock front. Adapted from Low (2001) and Hundhausen (1987).

4. CONCLUSIONS

Our previous study of SEPs in fast-wind regions (KR03), limited by poor statistics, could not confirm the existence of SEP events in fast-wind regions nor, assuming their existence, whether their associated CMEs were necessarily faster than those associated with other SEP events. This expanded study now shows both the existence of SEPs originating in fast-wind regions and no requirement for those associated CMEs to be significantly faster. This result seems consistent with coronal wave propagation observed in association with fast CMEs, but the relatively weak suprathermal tails in the ion speed distributions remains a problem for SEP production by shocks in the fast-wind regions.

I acknowledge extensive use of the LASCO CME catalog. This CME catalog is generated and maintained by the Center for Solar Physics and Space Weather, The Catholic University of America, in cooperation with the Naval Research Laboratory and NASA. *SOHO* is a project of international cooperation between ESA and NASA. I also acknowledge use of the *ACE* SWICS level 2 data posted on the *ACE* web page and thank D. Reames for the EPACT energetic particle data.

REFERENCES

Bamert, K., et al. 2002, J. Geophys. Res., 107, SSH 6-1
Desai, M. I., Mason, G. M., Dwyer, J. R., Mazur, J. E., Gold, R. E., Krimigis, S. M., Smith, C. W., & Skoug, R. M. 2003, ApJ, 588, 1149
Desai, M. I., Mason, G. M., Dwyer, J. R., Mazur, J. E., Smith, C. W., & Skoug, R. M. 2001, ApJ, 553, L89
Gabriel, A. H., Bely-Dubau, F., & Lemaire, P. 2003, ApJ, 589, 623
Gloeckler, G. 1999, Space Sci. Rev., 89, 91
Gloeckler, G. 2003, in AIP Conf. Proc. 679, Tenth Int. Solar Wind Conf., ed. M. Velli, R. Bruno, F. Malara, & B. Bucci (New York: AIP), 583
Gloeckler, G., Fisk, L. A., Zurbuchen, T. H., & Schwadron, N. A. 2000, in AIP Conf. Proc. 528, Acceleration and Transport of Energetic Particles Observed in the Heliosphere, ed. R. A. Mewaldt, J. R. Jokipii, M. A. Lee, E. Möbius, & T. H. Zurbuchen (New York: AIP), 221
Gloeckler, G., et al. 1998, Space Sci. Rev., 86, 497

Gosling, J. T., Hildner, E., MacQueen, R. M., Munro, R. H., Poland, A. I., & Ross, C. L. 1974, J. Geophys. Res., 79, 4581
Hundhausen, A. J. 1987, in Proc. Sixth Int. Solar Wind Conf., ed. V. J. Pizzo, T. Holzer, & D. G. Sime (TN-306; Boulder: NCAR), 181
Kahler, S. W. 1994, ApJ, 428, 837
———. 2001a, in Space Weather, ed. P. Song, H. Singer, & G. Siscoe (Geophys. Monogr. 125; Washington, DC: AGU), 109
———. 2001b, J. Geophys. Res., 106, 20947
Kahler, S. W., Burkepile, J. T., & Reames, D. V. 1999, Proc. 26th Int. Cosmic-Ray Conf. (Salt Lake City), 6, 248
Kahler, S. W., & Reames, D. V. 2003, ApJ, 584, 1063 (KR03)
Low, B. C. 2001, J. Geophys. Res., 106, 25141
Mason, G. M., Mazur, J. E., & Dwyer, J. R. 1999, ApJ, 525, L133
Mewaldt, R. A., et al. 2003, Proc. 28th Int. Cosmic-Ray Conf. (Japan), 6, 3229
Mobius, E., et al. 2002, Geophys. Res. Lett., 29, 1
Schwadron, N. A., Fisk, L. A., & Gloeckler, G. 1996, Geophys. Res. Lett., 23, 2871
Sheeley, N. R., Jr., Hakala, W. N., & Wang, Y.-M. 2000, J. Geophys. Res., 105, 5081
St. Cyr, O. C., Burkepile, J. T., Hundhausen, A. J., & Lecinski, A. R. 1999, J. Geophys. Res., 104, 12493
Teriaca, L., Poletto, G., Romoli, M., & Biesecker, D. A. 2003, ApJ, 588, 566
Tylka, A. J., Cohen, C. M. S., Dietrich, W. F., Maclennan, C. G., McGuire, R. E., Ng, C. K., & Reames, D. V. 2001, ApJ, 558, L59
von Rosenvinge, T. T., et al. 1995, Space Sci. Rev., 71, 155
Wang, Y.-M. 2000, ApJ, 543, L89
Wang, Y.-M., & Sheeley, N. R., Jr. 2003, ApJ, 587, 818
Wu, S. T., Andrews, M. D., & Plunkett, S. P. 2001, Space Sci. Rev., 95, 191
Zank, G. P., Rice, W. K., Le Roux, J. A., & Matthaeus, W. H. 2001, ApJ, 556, 494
Zhang, J., Woch, J., Solanki, S. K., von Steiger, R., & Forsyth, R. 2003, J. Geophys. Res., 108, SSH 1-1
Zurbuchen, T. H., Fisk, L. A., Gloeckler, G., & von Steiger, R. 2002, Geophys. Res. Lett., 29, 66-1

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
17-01-2006

REPRINT

4. TITLE AND SUBTITLE
Solar Fast-Wind Regions as Sources of Shock Energetic Particle Production

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
61102F

6. AUTHOR(S)
S.W. Kahler

5d. PROJECT NUMBER
2311

5e. TASK NUMBER
RD

5f. WORK UNIT NUMBER
A1

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory/VSBXS
29 Randolph Road
Hanscom AFB MA 01731-3010

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-VS-HA-TR-2006-1015

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL/VSBXS

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited.

13. SUPPLEMENTARY NOTES
REPRINTED FROM: THE ASTROPHYSICAL JOURNAL, Vol 603, pp 330-334, March 1, 2004.

14. ABSTRACT

If the production of solar energetic particles (SEPs) near the Sun is due to shocks driven by coronal mass ejections (CMEs), then two factors might favor SEP acceleration in slow rather than fast solar wind streams. The first is that both the MHD fast-mode and solar wind flow speeds are higher in the fast-wind streams. The second is that shock seed populations in the fast-wind streams consist of weak suprathermal ion tails with soft spectra. An earlier study used observed fast west-limb or halo CMEs and solar wind O^{+7}/O^{+6} ratios to compare associated SEP events and fast CMEs in fast wind with those in slow wind. Properties of the few fast CMEs in fast-wind regions suggested a bias in terms of associated SEP event size and/or CME speed against shock production of SEPs in fast-wind regions. Here the previous 1998–2000 study is expanded through 2002. The results of the much larger event sample now show no significant bias against SEP production in fast-wind regions. We discuss the implications of this result for shock seed populations and for shock propagation in coronal fast-wind regions.

15. SUBJECT TERMS
Sun Corona Corona mass ejections Particle emission

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
					S. W. Kahler
a. REPORT		**c. THIS PAGE**			**19b. TELEPHONE NUMBER** *(include area code)*
UNCLAS	UNCLAS	UNCLAS	SAR	10	781-377-9665

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. 239.18